Levelized cost of Electricity (LCOE) for Solar Building Integrated Photovoltaic (BIPV) system

by

+++Bill N. Nunneh (Brac University & University of Liberia)

#Abdiaziz Ali Nur **(Brac University)**

Abstract

The utilization of solar energy is most concerned source in energy sector nowadays. The building integrated photovoltaic solar panels are increasingly constructed in dense urban areas because theybrought many advantages to the society along with energy saving features. However, at the same time, they raise tensions in capital investments and overall returns. In this project, the BIPV systemis integrated on a multi-stair building consists of 6 floors, this building is located in Mogadishu, Somalia. The energy demand of the building is calculated also the power demand of the building is found to be 31 kW and average daily solar irradiation of this place is 4.8 kWh/m^2. The design of the project is carried out to show the connection of the solar panels. The total energy generated by BIPV system over 25 years is evaluated. In the report the Levelized Cost of Electricity (LCOE)of the BIPV system is calculated by considering all parameters related to LCOE. the electricity tariff of Somalia is also found to compare that the project meets grid parity or not, the result of thatcomparison is shown. The income sources of the project including the power delivery cost, transmission line cost is also considered. The result and figures are shown in this project.

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1. Introduction

The sun is a source of solar energy in our solar system. Solar energy exists into two forms that can be used into electrical conversion, the Photovoltaic (PV) and solar thermal. The process in which solar light is directly converted into electricity is called photovoltaic effect. The most common type of photovoltaic in the world today is made up of silicon element. The three main PV market today are Building-Integrated Photovoltaic (BIPV), Residential rooftop and Ground-mounted system or Utility Integration system [1]. During recent years, there has been an increasing interest in building integrated photovoltaic systems (BIPV). BIPV refers to PV systems that not only generate clean electricity but also behave like skin cover for a building, the most crucial advantage of BIPV systems compared to other alternatives in urban areas is that the BIPV system is located on the closest distance to the end-user, and it does not need land to produce electricity [2]. In this report the economic feasibility of Building Integrated PV (BIPV) system is located in Mogadishu Somalia and it is presented by using Levelized Cost of Electricity (LCOE) to compare to residential tariff in Somalia. The levelized cost of Electricity ("LCOE") calculation is used in the electric power industry to rigorously compare different ways of sourcing electricity [3]. The LCOE of an energy-generating asset can be thought of as the average total cost of building and operating the asset per unit of total electricity generated over as assumed lifetime [4]. This project is organized as follows, the section 2 discussed the components and project design. Sector three the parameters of the project and calculation of Levelized cost of electricity. The 4th section reports the result generated from using excel. Unit 6 is written by the analysis and discussion. At last, the conclusion part is reported in section 7.

2. Components of PV System Design

Solar photovoltaic (PV) energy systems are made up of different components. The type of component in the system depends on the type of system and the purpose. A solar energy system produces direct current (DC). This is electricity which travels in one direction. This section will present the different solar PV system components and describe their use in the different types of solar PV systems [6]. the design of BIPV system is also discussed in this section. The size of the system is also calculated. We will have considered the daily full sun hours of Mogadishu, Somalia.

2.1. Proposed System Design

This survey is based on a residential building that is located in Mogadishu, Somalia and as the result of that we want to design a project on the residential multi-stair building consists of 6 floors, each floor consists of 2 flats, and each flat consists of 3 rooms, 2 toilets, 1 kitchen and 1 dining room. Each flat uses the essential electrical appliances such as light bulbs, ceiling fans and refrigerators, all these appliances are calculated. There are also some other electrical appliances that are not in use regularly, combining all of those appliances we assume some daily power consumption. The building is located in the capital city of Somalia, according to [6], solar energy in this place is good, the daily sun hours of Mogadishu is 6 hours, so it has daily full sun hours of 4.8 KWhr/m^2, as shown in the fig 1.

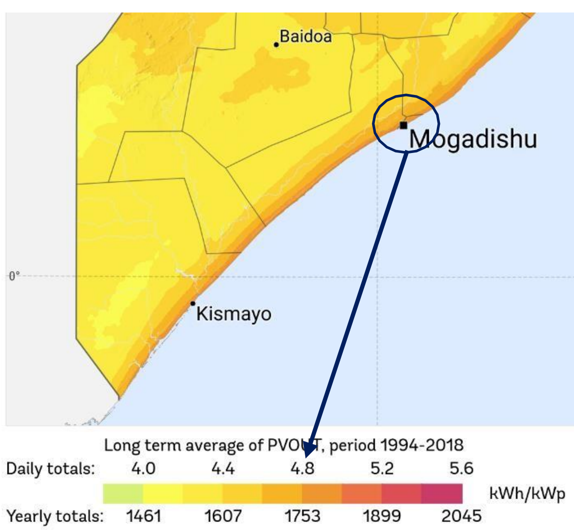

Fig.1 Incident solar energy of Mogadishu, Somalia [2]

2.2. Energy Demand Calculations

First each flat daily energy consumption will be calculated, then it is multiplied by 2 that is two flats on each floor. Then again, it will be multiplied by 6 that is the number of floors of the building.

Table-1. Flat load calculation

No	Name	Quantity	Power rated	Hours used	Daily energy consumption (Whr/day)
1	LED Light bulb	6	7	5	210
2	Light bulbs	5	60	5	1500
3	Ceiling fan	4	100	10	4000
4	Laptop	5	60	2	600
5	Refrigerator	1	150	8	1200
6	Washing machine	1	500	2	1000
7	Cooker	1	200	3	600
8	TV	1	75	5	275
9	Other	Other	Other	Other	500
					Total = 9885 Whr/day
					9.885 kWhr/day

As shown in the calculation of one flat the daily energy consumption is 9.885 kWhr/day, we assume that all other flats are the same to the first flat, so 2 will be multiplied to get the first-floor dailyenergy consumption.

$$9.885\,\frac{KWh}{day} \times 2 = 19.77\,\frac{KWh}{day} - - - - - - - - - - - \longrightarrow one\ floor\ daily\ energy\ consumption.$$

Now, daily energy consumption of whole building is calculated below.

$$19.77\ \frac{kWhr}{day} \times 6 = 118.62\ \frac{kwhr}{day} - - - - - \longrightarrow all\ building\ daily\ energy\ consumption$$

$$118.62\ \frac{kwhr}{day} \times 365 = 43296.3\ kWh - - - - \longrightarrow all\ building\ yearly\ energy\ consumption$$

Table-2 summary of energy consumption

Flat daily energy consumption (kWhr/day)	Floor daily energy consumption (kWhr/day)	Building daily energy consumption (kWhr/day)	Building yearly energy consumption (kWhr/year)
9.885	19.77	118.62	43296.3

Table two shows the summary of energy usage of the building, in daily and in yearly. As shown in table 2, the daily energy consumption is multiplied 365 days in a year so the output is 43296.3 kWhr/year.

2.3.PV Sizing.

When calculating the size of power of PV system, we referred to the above annual energy demand on the building. The above table is needed along with daily full sun hours, that is the amount of energy available in a fixed place in a day. As shown in first fig.1 we get the daily full sun hours of Mogadishu city is 4.8 kWh/day.

$$\text{Anual full sun hours} = 4.8\ \text{kWhr} * 365 = 1752\ \text{kWhr/year}$$

$$\text{PV System Size} = \frac{\left[\frac{\text{energy demand}}{\text{anual full sun hours}}\right]}{\text{efficiency loss}}$$

$$= \frac{\left[\frac{43296.3}{175}\right]}{0.8}$$

$$= \frac{19.125}{0.8} = 31\ kW$$

2.4. PV Modules and PV Area Calculation

The majority of photovoltaic modules available on the market that are used for residential and commercial solar systems are silicon crystalline as stated in the introduction. Crystalline silicon Photovoltaic modules are two types, monocrystalline and polycrystalline as shown in fig.2. in this report 330 W monocrystalline solar modules are used. The number of PV modules form an array. The calculation of the number of modules needed to produce the system size that we have considered (31 kW) is presented here.

$$\text{Watt pick} = \frac{\textit{system size in W}}{\textit{dialy solar iradiation}}$$

$$\text{Watt pick} = \frac{31000\ W}{4.8} = 6458.333\ \text{Wp}$$

$$\text{number of solar panels} = \frac{\text{watt pick}}{\textit{one panel power rate}}$$

$$\text{number of solar panels} = \frac{6458.333\ \text{Wp}}{330\ \text{W}} = - - - -\!\!\longrightarrow 20\ \text{panels}$$

(a) (b)

Fig. 2 a) monocrystalline b) polycrystalline

The calculation of an area of the building that is needed for installing BIPV system is performed here. To design the building that can be integrated photovoltaics. We considered the dimension of one module to be 1.675 x 0.997 m = 1.7 m^2.

$$\text{Area} = 1.7 \times 20 = 34\ \text{m}^2$$

The building-Integrated Photovoltaic (BIPV) is the solar photovoltaic that is integrated to the building, so this area in not needed to build a solar PV only but it is also the area of the building and the PV system covered this portion of the building. So, the roof top of the building length and width must be 6 m × 5.5 m as shown in fig.3

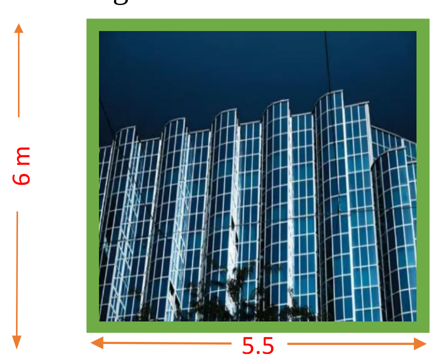

Fig.3 Area needed

The cost per watt of solar panel in Somalia is \$0.50/watt. The cost of one module = 330 w × \$0.50 = \$165. The total cost of system modules = 20 × \$165 = \$3,300. This is the initial investment cost of solar modules.

2.5. Connection of Modules.

The open circuit voltage of each panel is 41.0 V, short circuit current of each module is 9.55 A. As calculated above the number of panels is 20. The voltage range of an inverter is between 300-480 VDC. The fig.4. shows connection diagram of the PV modules.

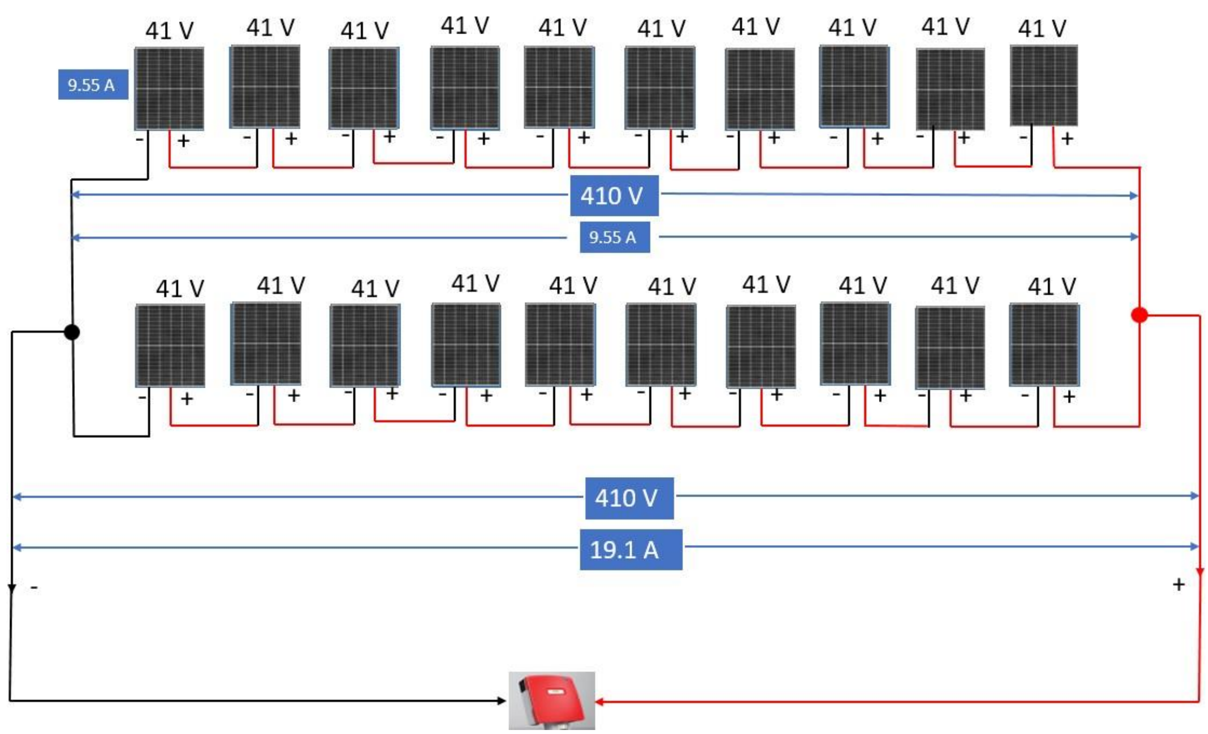

Fig.4 Project Connection Layout

2.6. Inverter Selection

Energy from an array is direct current (DC). But the most residential appliances operate on alternating current (AC), so the current needs to be converted. The inverter changes DC energy to AC energy. Inverters are available in many different sizes for various-sized loads. Larger inverters are available to power larger loads. A string inverter is used to convert DC power from a solar array to AC power and can be connected to an AC distribution power panel (service panel) in a

residence, and/or can be connected to the grid. String inverters are available in different sizes depending on the size of the AC loads. In this study we have selected SMA Sunny Boy 10,000TL-US-12 inverter as shown in fig.5, based on the market availability in Somalia. The cost of one 10 KW inverter is $3,004,

$$number\ of\ 10\ KW\ growatt\ inverters = \frac{system\ size}{inverter\ rating} = \frac{6458.333\ \text{Wp}}{10{,}000\ W} = 1\ pc$$

$$the\ initail\ cost\ of\ the\ inverters = 1 \times \$3{,}003 = \$3{,}004$$

Fig. 5 Three phase inverter. [8]

2.7. Other Components

SN	Name	Quantity	Unit price	Total price
1	4 mm^2×4core Cables	1000 meter	$1.5	$1500
2	Energy Meter	1	$85	$85
3	Changeover/ATS	1	$100	$100
4	Siemens Q220 20 Amp Dual Pole Circuit Breaker	1	$15	$15
5	Installation cost	Other	Other	$600

Total =$2,300

2.8. Supporters

The building-Integrated PV (BIPV) system does not need tiling for installation upkeep because it is integrated to the building itself. Subsequently, it works double purpose, to generate clear energy and to cover the building.

3. Parameters for LCOE Estimation

This Project proposed a method for calculating the levelized Cost of Electricity (LCOE) of the BIPV system. This section will discuss factors and parameters that need to be defined in order to develop the LCOE for the project.

3.1. Initial Investment Cost

The initial investment cost of our system consists of solar panels, inverters and cables as discussed in section 2. We calculated the summation of that costs here:

$$\text{IiCost} = \text{The total cost of solar panels} + \textit{the initail cost of the inverter} + \textit{other costs}$$

$$\$3{,}300 + \$3{,}004 + \$2300 = \$8{,}604$$

3.2. Operation and maintenance (O&M) costs

Once the BIPV system has been implemented, it needs to be carefully maintained and efficiently operated. Compared to other alternatives, the BIPV system has low servicing requirements and maintenance. Annual operation and maintenance (O&M) expense of a BIPV system is assumed to be 0.5% of the initial cost of BIPV system for this project. The operation and maintenance cost can be calculated as flows:

$$O\&MCost = 0.005 \times IiCost \times Project\ lifetime = 0.005 \times \$8{,}604 \times 25 = \$1{,}075.5$$

3.3. Inverter replacement cost

the inverter replacement cost of each year is a 10% of the initial investment cost of our project, since we the project life cycle is 25 years each 10 year, the inverter must be replaced, so we need three inverters during 25 years, and can be calculated by using this formula:

$$IrCost = Initial\ investment\ Cost \times 0.1$$

$$IrCost = \$8{,}604 \times 0.1 = \$860.4$$

3.4. System Cost

The cost of the system is the investment, operation and maintenance and inverter replacement cost, so $\text{NPVC} = \text{IiCost} + \text{IrCost} + \text{O\&MCost}$

$$\text{NPVC} = \$8604 + \$860.4 + \$1{,}075.5 = \$10{,}540$$

3.5. BIPV degradation rate

Regardless of the environment that solar cells of the BIPV system are in, they naturally degrade over time, which is called the BIPV degradation rate. The degradation depends on the location. In Somalia we found that the median degradation rate of solar cells is 0.5% per year.

3.6. System Energy Production

Section 2, we have calculated the first-year electricity production of BIPV systems and it naturally degrades over time, and the decreased ratio is called the BIPV degradation rate. Depending on the material, the BIPV degradation rate varies as mention above the degradation rate of this project is 0.5% per year. The total electricity production of the system over its lifespan can be calculated as indicated here:

$$E_{GT} = E_{G1} \sum_{n=1}^{N} (1 - R_{EG})^{N}$$

Given that,

E_{G1}= *Energy generated by the Building Integrated PV in the 1st year.*

N= *Total number of years the PV system operates (usually equal to its warranty period)*

G_{EG}= *Degradation rate of the system.*

For example: $E_{G-second\ year} = 43296.3\text{kWh} \times (1 - 0.005)^{2} = 42864.42\ \text{kWh}$

we will have continued this calculation by using excel, until the life cycle of the project that is 25 years.

3.7. Income Sources of our project

In this sub-section of the project, we discussed the sources of the project income.

3.7.1. Power delivery cost

BIPV system provides a way to reduce or even omit the capital expenditure required to expand the grid's electric network infrastructure or maintenance. generated electricity by a BIPV system can decrease the delivery cost of around 20% of the total electricity price. The delivery cost covers expenses for distribution equipment that deals with lower voltages, the transmission costs, charges

for installing, operating, and maintaining meters and sensors etc. so we have calculated the power delivery cost by using this formula.

$$P_d Income = \sum_{n=1}^{N} E_{Gn} \times R_{pd} \times \frac{P_{grid_{price}}}{(1 + R_{dis})^n}$$

Given that,

$P_d Icome$ = power delivery cost

E_{Gn}= *Energy generated by the Building Integrated PV in the nth year.*

N= *Total number of years the PV system operates usually 25 years.*

R_{pd} *= power delivery saving rate that is 20%*

$P_{grid_{price}}$ = grid price.

R_{dis} = discount rate that is 5% of our system.

3.7.2. Transmission line lost power

The generated electricity will be consumed by the residents of the building or the neighboring buildings, which leads to the elimination of transmission line losses. According to the USAID data [9], the electrical power transmission line loss in Somalia is 40% due to poor infrastructure and collection. Thus, saving that cost we can earn some incomes of our project. To calculate the Transmission line cost we have used this formula in excel.

$$T_L Income = \sum_{n=1}^{N} E_{Gn} \times R_{TR} \times \frac{P_{grid_{price}}}{(1 + R_{dis})^n}$$

given,

$T_L Income$ = Transmission line lost income

E_{Gn}= *Energy generated by the Building Integrated PV in the nth year.*

N= *Total number of years the PV system operates usually 25 years.*

R_{Tr} = Transmission line loss rate that is 4*0%*, in our system.

$P_{grid_{price}}$ = grid price in nth year.

R_{dis} = discount rate that is 5% of our system.

3.7.3. Societal cost of carbon (SCC)

The societal cost of carbon (SCC) is the total damage caused by greenhouse gas emissions (GHG). The SCC, which is also called the shadow price of carbon, is a principal measure of the global incremental damage accomplished by GHG emission. There is no data related SCC available in Somalia, therefore we are not including the values of SCC here, but this project generates the clean energy and can save this cost.

3.7.4. Saving of the building material

In the BIPV system, the building is covered by the solar panels, which works as double purpose material, it generates the electricity and also gives the building envelope for protection. Thus, some building material will be saved here and it can be one of the sources of income. The saving cost of the building materials in this project is $2,500.

3.7.5. Energy Generated Income

The excess energy generated by BIPV system can be delivered to the utility grid and we can earn some income that is called energy generated income and can be calculated by the below equation.

$$E_{GI} = \sum_{n=1}^{N} E_{Gn} \times \frac{P_{grid_{price}}}{1 + R_{dis}}$$

therefore,

E_{GI} = Energy generated income

E_{Gn}= *Energy generated by the Building Integrated PV in the nth year.*

N= *Total number of years the PV system operates usually 25 years.*

$P_{grid_{price}}$ = grid price in nth year.

R_{dis} = discount rate that is 5% of our system.

3.8. LCOE Calculation

Now we can calculate the LCOE, or levelized cost of electricity that is a term which describes the cost of the power produced by solar over a period of time, typically the warranted life of the system. LCOE can be calculated using this formula:

$$\text{LCOE} = \frac{\sum_{n=1}^{N} NPV}{E_{G1} \sum_{n=1}^{N} (1 - R_{EG})^{N}}$$

We have calculated the net present value of the project using this formula.

$$\text{NPV} = \text{Cash flow} - \text{sytem investment cost}$$

We have used these formulas in Microsoft excel to generate the figures and to present them.

4. Results (figures and tables)

The results and figures are generated by using Microsoft excel and we will present in this section. Fig.6 illustrates the electricity price per unit kWh in Somalia since it shows the decreases inclination still the tariff cost is very high as shown in the fig.6. The tariff in Somalia is a uniform rate tariff.

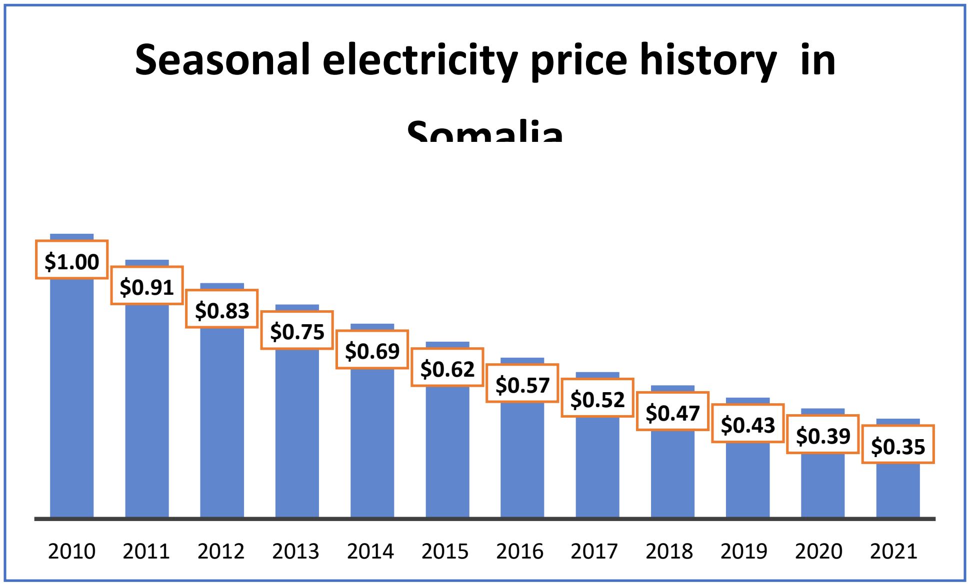

Fig.6 Present and past history of Somalia residential tariff

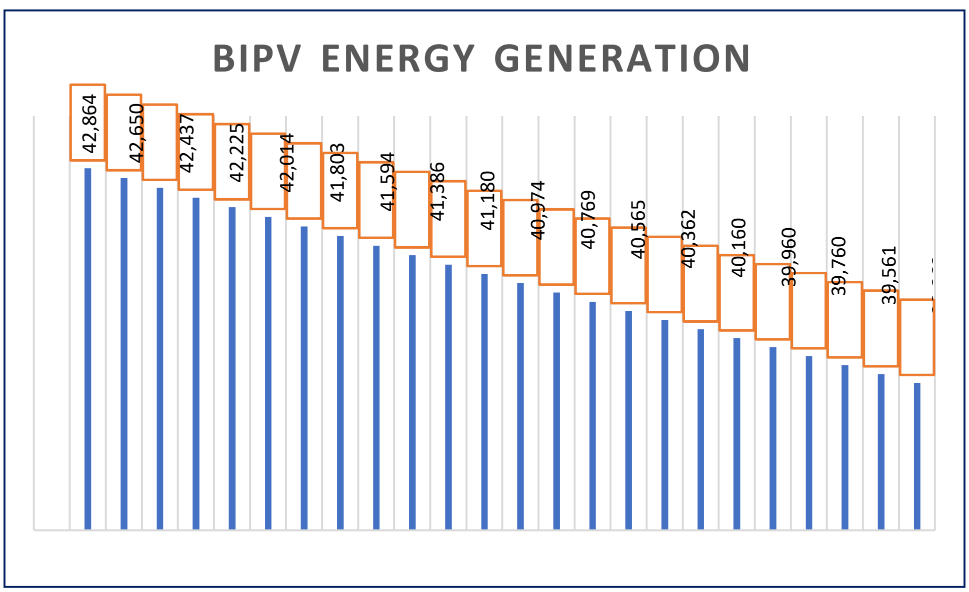

Fig.7 Electricity production of BIPV system for 25 years

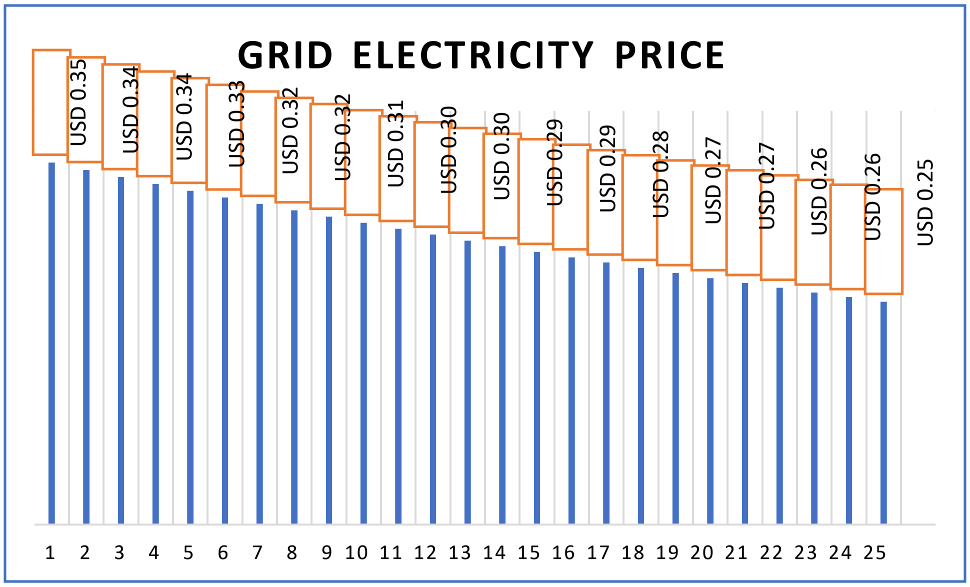

Fig.8 Grid Electricity inflation price of project life time.

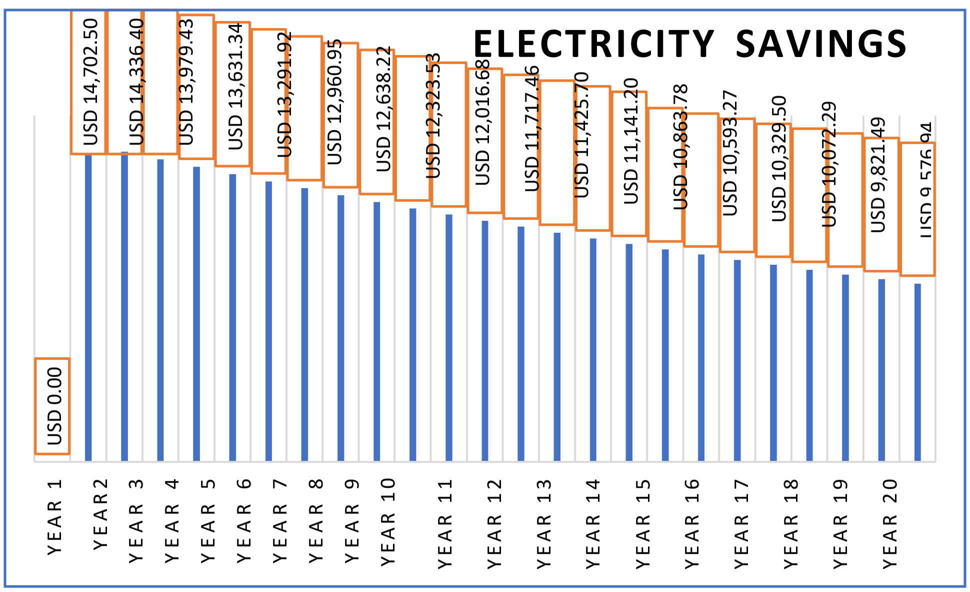

Fig.9 Electricity saving cost annually

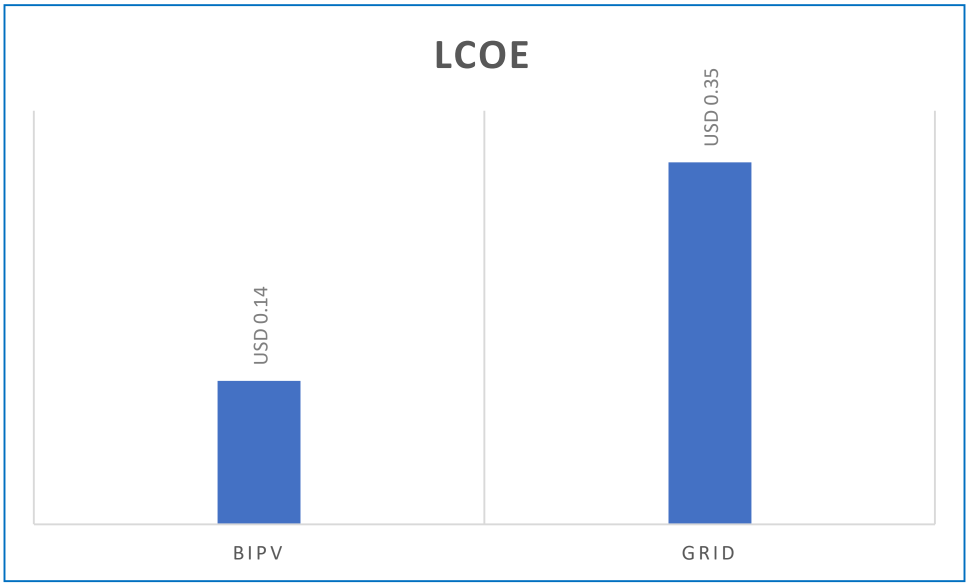

Fig.10 Comparison of BIPV system and Grid LCOE.

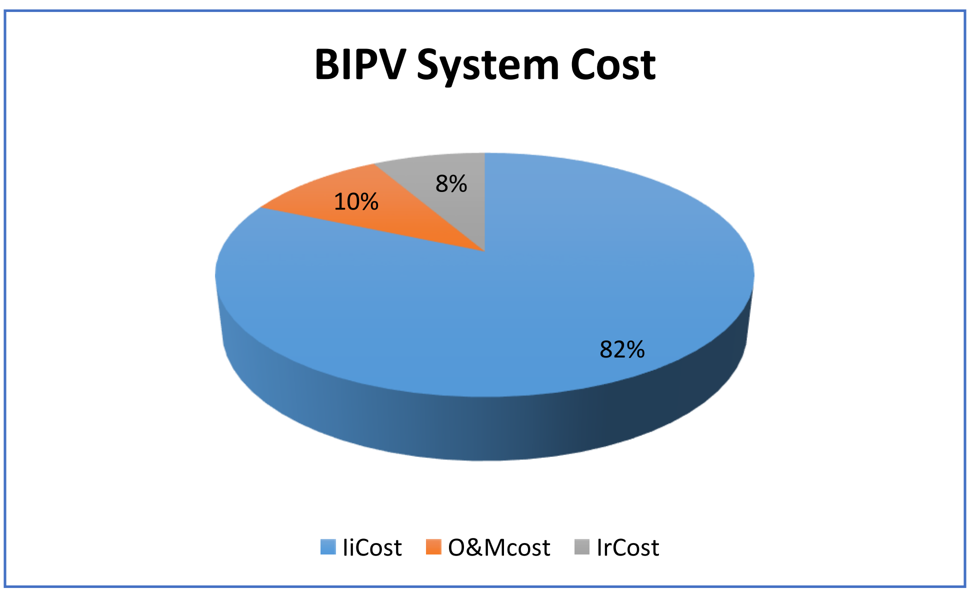

Fig.11 Project system Cost

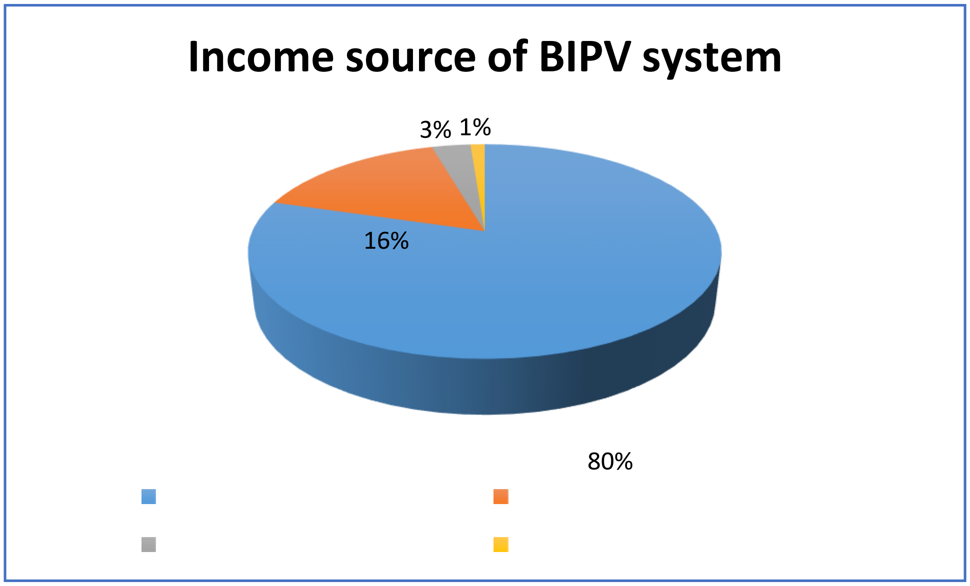

Fig.12 Income of our project

Table 3 Electricity tariffs, electric power transmission losses rate and power delivery ratein Somalia

Electricity tariffs	Transmission line loss	Power delivery rare
$0.35/kWh	40%	20%

Table 4 system cost summary

1	Initial Investment Cost	$8,604
2	Operation and maintenance (O&M) costs	$1,075.5
3	Inverter replacement cost	$860.4

Table 5 system income summary

1	Energy Generated Income	$169,730.98
2	Power delivery cost	$33946.2
3	Transmission line lost power costs	$6,782.39
4	Saving of the building material	$2500

5. Analysis and Discussion

In this proposal, it is observed that the use of the BIPV system will reduce the amount spent on yearly power generation by 60%. This is because the electricity cost in Mogadishu on the grid as shown in fig. 9 is **$0.35** and with the BIPV system the LCOE is **$0.14** which is 40% of the amount spent when using a grid. In this way we are able to save **$0.21**. The use of the BIPV system will save the cost of transmission line because the system will be attached to the building for which this power has been generated. Also, the societal cost of carbon which leads to greenhouse emissions is completely negligible it is a clean energy system and therefore the amount needed for the cost of replenishing the atmosphere is been save. Furthermore, the power generation income is huge and is capable of keeping up the maintenance over the duration of 25 years for the degradation period and for a complete replacement. Considering these analysis and calculations made within this project it is advisable to carry out such investment that is more beneficiary than that of an investment in grid that is cost intense. Improvement can be made to increase the 31kW of power generated from this project to 100kW and above depending on the demand. In fig. 3, it is shown that increasing the size of the PV will also result in the increase in the power generated from the sun therefore if the demand for more power is require there will be a high efficiency in generation process and this will also lead to an increase in the initial investment.

6. Conclusion

In this paper we concentrated on Building-Integrated photovoltaic (BIPV) system for residential application in a particular region of Somalia. It is designed such that the PV system can input or output abundantly the electricity to the residential building and the utility electricity grid. The objective of this project is to minimize and fixed the annual energy cost of the building. The project indicates the PV capacity that the customer must adopt with their electricity requirements. Using this design PV system, we calculated and investigated the economic impact of the PV system initial investment under several conditions for a typical residential building located in Mogadishu, Somalia. Additionally, the sensitivity of levelized cost of electricity (LCOE) and simple payback period to various economic and technical circumstances has been analyzed. Therefore, investment in this project is considered more beneficiary and is applicable to other parts of the world since there is 60% reduction in the cost of electricity on the grid.

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